SYNTHESIS OF SIMULATED LUNAR HIGHLANDS MINERALS

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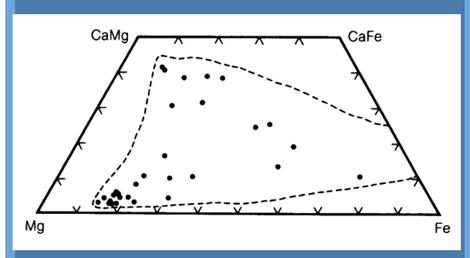
53rd Lunar and Planetary Science Conference, 03/09/2022

ABSTRACT

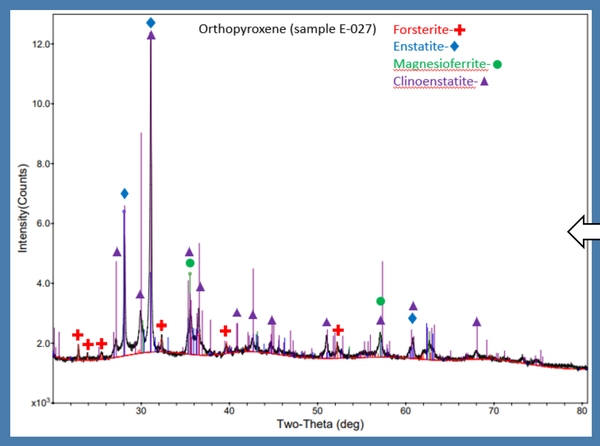
- This work focuses on the development of synthetic lunar minerals, to enable customizable powder production of synthetic lunar regolith simulants
- Highlands regolith comprised mostly of four minerals; high calcium plagioclase, clinopyroxene, orthopyroxene and olivine.
- Laboratory synthesis of these minerals has been demonstrated with scalable methods.
- Scale-up achievable by leveraging existing manufacturing methods currently producing multi tons of granular powder for other industries

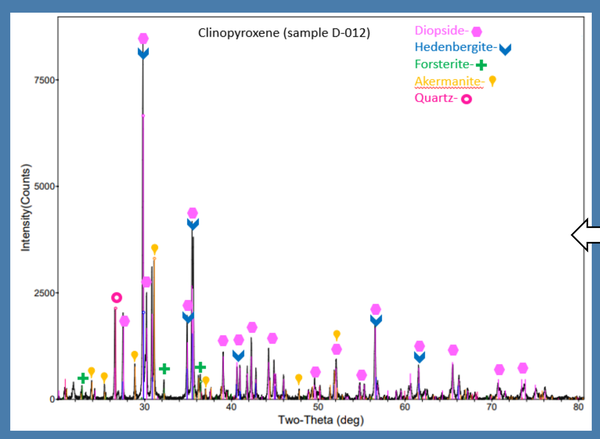
BACKGROUND

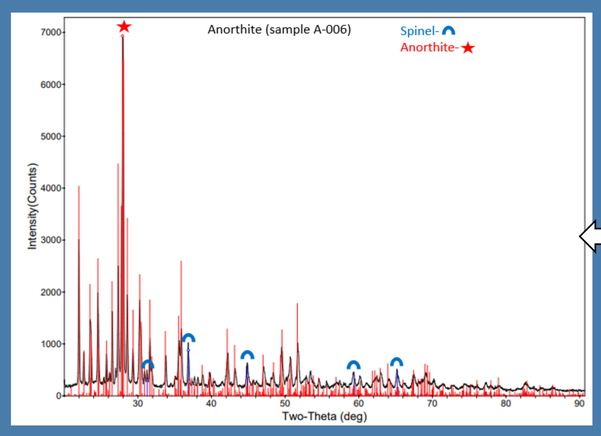
- Highlands lunar regolith >96% 4 mineral types; Calcium Plagioclase (anorthite), Orthopyroxene (enstatite), Clinopyroxene (diopside), and Olivine.
- High purity olivine readily available commercially, others require synthesis due to scarcity on Earth
- Lunar mineralogy is heavily reduced, deplete of alkali elements, no weathered minerals
- This study focuses on both Pyroxene types and Calcium Plagioclase synthesis
- Synthesis targets for pyroxene minerals fall close to the Diopside and Enstatite end members (shown below on left)



Pyroxene quadrilateral with known lunar Highlands compositions. Pyroxenes trend towards Enstatite and Diopside end members, with Fe replacing Mg on the M1 site. (Lunar Sourcebook)



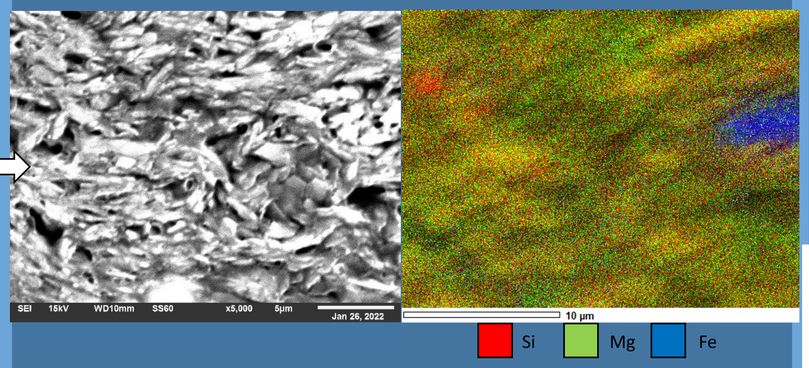


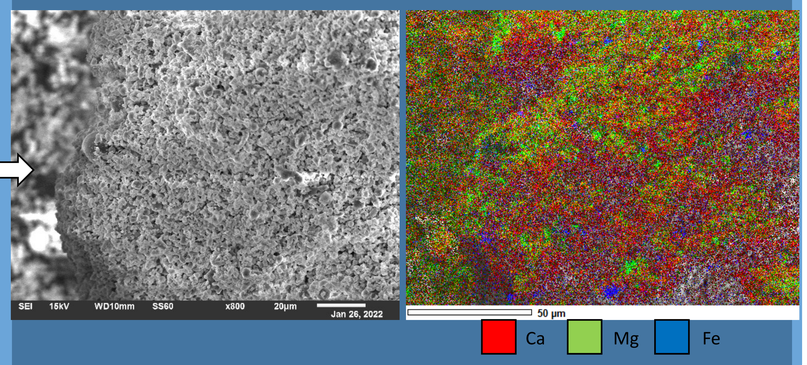


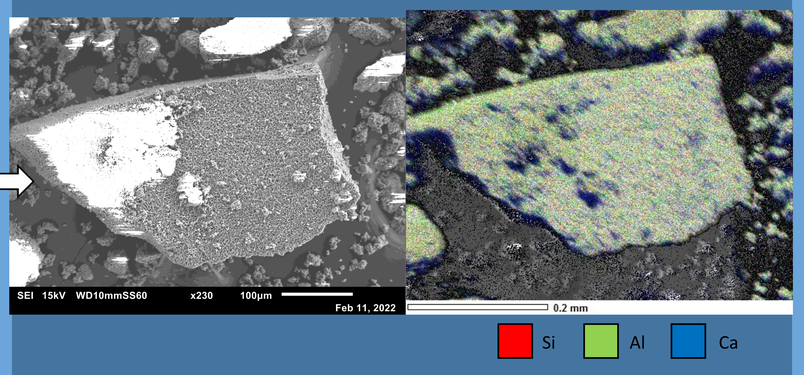
RESULTS: X-RAY DIFFRACTION (XRD)

- Top: XRD orthopyroxene. Major phases Enstatite and Clinoenstatite.
- Minor forsterite and magnesioferrite spinel.
- Magnesioferrite indicates appropriate oxygen fugacity.
- Clinoenstatite introduced during sample preparation, due to shear induced phase transformations.
- Middle: XRD pattern clinopyroxene. Major phase Diopside.
- Minor phases of Hedenbergite, Forsterite, Akermanite, and Quartz.
- Hedenbergite is a desirable pyroxene end member.
- Forsterite and akermanite acceptable in lunar minerals
- Quartz can be removed 1) by adding more Mg to drive to forsterite or 2) leaching process
- Bottom: XRD calcium plagioclase anorthite. Minor spinel, likely from Mg contamination in Ca raw material.

Secondary Electron Imaging EDS Map



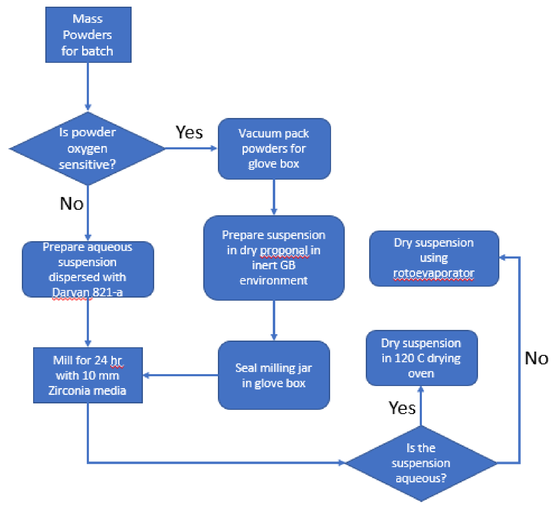




RESULTS: SCANNING ELECTRON MICROSCOPY (SEM) AND ENERGY DISPERSIVE SPECTROSCOPY (EDS)

- Top Left: SEM orthopyroxene shows typical texture of synthetic enstatite, elongated grains characteristic of orthopyroxene crystals.
- Top Right: EDS Sample mostly homogenous, except for region enriched in Fe. Based on XRD this is likely a magnesioferrite grain. Fe was added at 5 at% replacing Mg.
- Middle Left: SEM clinopyroxene showing porous structure, possibly hard agglomerates
- Middle Right: Mostly homogenous, with some Mg and Fe rich regions, likely forsterite and hedenbergite present in XRD. Fe was added at 5 at% replacing Mg.
- Bottom Left: SEM anorthite showing porous structure. Sintered, difficult to grind
- Bottom Right: Homogenous, except for Ca rich region

METHODS



Target Mineral	Components	Crucible	Furnace atmosphere	Temperature (time at)
Anorthite ($CaAl_2Si_2O_8$)	Alumina, Silica, Calcium Carbonate	Alumina	Air	1300 C (5 hr)
Orthopyroxene ($(Mg_{0.95}Fe_{0.05})SiO_3$)	Talc, Magnesium Carbonate, Iron	Alumina	Airgas UHP-Ar (1 PPM O_2 impurity)	1040 C (5 hr)
Clinopyroxene ($(CaMg_{0.9}Fe_{0.1})Si_2O_6$)	Calcium Carbonate, Magnesium Carbonate, Silica, Iron	Alumina/ Platinum	Airgas UHP-Ar (1 PPM O_2 impurity)	1250 C (5 hr)

CONCLUSIONS

- Three major constituent minerals of Highlands regolith synthesized with scalable ceramic processing methods.: anorthite, orthopyroxene (enstatite), and clinopyroxene (diopside)
- Anorthite was effectively synthesized using alumina, silica, and calcium carbonate fired at 1300 °C in air
- Ferrous orthopyroxene was effectively synthesized using talc, magnesium carbonate, and metallic iron powder fired at 1040 °C in UHP-Ar.
- Ferrous Clinopyroxene was effectively synthesized from silica, magnesium carbonate, calcium carbonate and metallic iron at 1250 °C in UHP-Ar
- Minor phases present in pyroxene samples indicate that the oxygen fugacity was at an appropriate level for synthesis. No indication of ferric iron, only ferrous iron within mineral phases.

Research partially funded by NASA and DrHollyShulman, LLC.